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Environmental Factors Governing the Infection of Mussels, *Mytilus edulis*, by *Mytilicola intestinalis*

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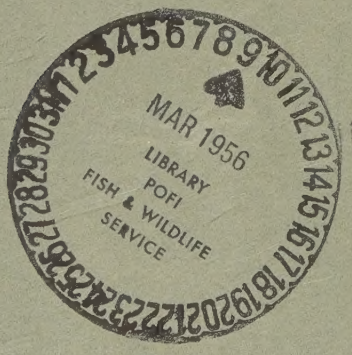

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1955

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Environmental Factors Governing the Infection of Mussels, *Mytilus edulis*, by *Mytilicola intestinalis*

INTRODUCTION AND REVIEW OF PREVIOUS WORK

Importance of Mytilicola

Mytilicola intestinalis Steuer, commonly called " red worm ", is a copepod of the family Mytilicolidae, living parasitically in the gut of molluscs. It is common in the mussel, *Mytilus edulis* L., at many points around the coast of Britain. It also occurs in oysters (Baird, Bolster and Cole, 1951), cockles and other molluscs (Hepper, 1953).

Cole and Savage (1951) have shown that *Mytilicola* is associated with loss of condition in mussels. Korringa (1951, 1952) attributed a sudden and heavy mortality in Dutch mussels to the presence of *Mytilicola* with serious physiological damage to the mussel, and (1953) states that *Mytilicola* interferes with the health, growth and fattening of the host. Odlaug (1946) concluded that the Olympia oyster, *Ostrea lurida* Carpenter, was harmed by the presence of *Mytilicola orientalis* Mori, a species closely related to *M. intestinalis*.

In view of the capacity of *Mytilicola* for causing damage to its hosts, it became a matter of urgent necessity, firstly, to determine the distribution of the parasite in Great Britain, particularly in the vicinity of commercial mussel beds; secondly, to determine the methods by which the parasite is conveyed from place to place; and, thirdly, if danger to the commercial mussel beds was established, to devise control measures to minimise as far as possible the damage which would occur in the event of those beds becoming infected.

In 1951-52 Bolster (1954) surveyed the distribution and studied the biology of *Mytilicola intestinalis* in England and Wales and concluded that investigations of possible control measures should be undertaken. It is with such investigations that the present paper is concerned.

Spread of Mytilicola

Mytilicola intestinalis was first described by Steuer (1902) from *Mytilus galloprovincialis* Lmk., the mussel of the Mediterranean, in the Gulf of Trieste. A number of workers have since reported the parasite as present at various points on the Italian, French and Spanish Mediterranean coasts. The first report of the parasite outside the Mediterranean was by Caspers (1939) who found it in the Cuxhaven area of Germany, although it has since become known that a specimen was taken at Southampton (England) in 1937 (Cole, 1951).

In 1947 Ellenby reported the parasite to be present at Blyth, Northumberland—the first published British report. There is an unconfirmed report that the parasite was present there in 1944.

In 1949 a heavy mortality of mussels occurred in Holland, this being attributed to the presence of *Mytilicola* (Korringa 1951, 1952). Since then the parasite has been reported from many points on the European North Sea and Atlantic coasts, from Germany (Schleswig-Holstein) to Portugal (River Tagus). Many of these reports arose out of a search stimulated by the disaster to the Dutch mussel industry.

The distribution of the parasite in the British Isles, as revealed by the work of Hockley (1951, south coast), Grainger (1951, Ireland), Thomas (1953, Scotland) and Bolster (1954, general), is as follows:

At Blyth, Northumberland (1947—possibly 1944)—an isolated infection; on the south-east coast (1949)—in most harbours and estuaries south of Southwold in Suffolk;

on the south coast (1950)—in many harbours and estuaries; in South Wales—from Milfor Haven eastwards; at Barrow (Lancs.) (1951)—an isolated infection.

In Ireland *Mytilicola* is present in the vicinity of Cork and in Co. Galway (Grainge 1951), and in Scotland in the firths of Clyde and Forth (Thomas, 1953).

Methods of Dispersal

The parasite has, during its life history, some free-living stages, but these are of onl short duration, normally no more than a few days, and certainly not long enough to perm the spread of the parasite over wide areas by currents save in very exceptional circumstance

Bolster (1954) has found that *Mytilicola* can live in mussels on the bottoms of ships, an the movements of such vessels probably comprise the main method of dispersal of th parasite. Dispersal of introduced forms by this method is by no means uncommon, a shown by Cole (1952) and Allen (1953). It is noticeable that isolated infections by *Mytil cola* occur in the region of ship-breaking and ship-repairing yards, suggesting that th parasite had been carried on ships destined for breaking up or refitting. In view of thes facts, no mussel bed can be considered safe from *Mytilicola*, since mussels can occur o even small yachts, and by this means any of the commercial mussel beds could becom infected.

Another possible source of infection is relaying or dumping of infected shellfis *Mytilicola* can infect a number of molluscs, and any of these, if relaid or dumped for an reason whatsoever, could infect a bed.

Life History

The adult *Mytilicola* of both sexes lives in the intestine of the mussel. Parasites a most commonly found in the loop of the recurrent intestine, which lies embedded in th digestive gland, and in the rectum. Young stages are frequently found in the stomac The gut of the host is often distended, and the parasites can easily be distinguished, the bright red colour showing clearly through the host's tissues, particularly in heavy infection

The male parasites may reach 5 mm. in length and the females 10 mm. The fema parasite, particularly in summer, is often seen to carry at the posterior end a pair of pin egg-sacs. From these hatch out nauplius larvae, which escape to the exterior, and, whil still free-swimming in the sea, metamorphose into metanauplii, and later copepodic The last is the infective stage, and, when taken in by the mussel with its food, enters th host's gut and completes the life cycle. Korringa (1951) has stated that from hatching the production of egg-sacs occupies about seven or eight weeks.

The nauplius stages of the parasite are positively phototactic and tend to swim near t surface of the sea. The copepodid, on the other hand, sinks to the bottom, but whether th is due to a negative phototaxis or to some other stimulus has not yet been clearly establishe The significance of this behaviour of the infective stage is referred to later.

It is generally accepted that *Mytilicola* breeds at water temperatures greater than 6° More detailed life histories are given by Steuer (1902 and 1905), Pesta (1907), Monod an Dollfuss (1932), Caspers (1939), Grainger (1951) and Hockley (1951).

Hosts

Mytilicola intestinalis, in addition to infecting the common edible mussel, *Mytilus edul* and the Mediterranean mussel, *Mytilus galloprovincialis*, has been reported from oyste *Ostrea edulis*, by Baird, Bolster and Cole (1951); the level of infection was low, abo 3-4 per cent. *Mytilicola* has also been found by the Author occurring naturally in a cock *Cardium edule*, from Poole Harbour. Artificial infections have been made in the laborato of *Paphia pullastra*, and *Crepidula fornicata*, the American slipper limpet, and also of t known natural hosts (*Ostrea*, *Mytilus*, *Cardium*) (Hepper, 1953).

Mytilicola orientalis Mori, a related species native to the Pacific Ocean, has been report by Odlaug (1946) in *Ostrea lurida*, *Ostrea gigas*, *Mytilus edulis*, *Paphia staminea*, a *Crepidula fornicata*. *Mytilicola porrecta* Humes, has been reported by Humes (195 from the ribbed mussel, *Modiolus demissus* Sowerby, the curved mussel, *Mytilus recurv*

Raf., and the quahaug, *Venus mercenaria* L. *M. porrecta* is found in the southern states of the U.S.A.

It has also been suggested (Humes *loc. cit.*, Monod and Dollfuss, 1932) that *Trochicola* Dollfuss (Dollfuss 1914), a parasite of the topshells, *Calliostoma zizyphynus*, *Gibbula cineraria*, and *Gibbula varia*, may be identical with *Mytilicola*, although this has yet to be proved; it is certainly very similar. Humes also points out the strong similarity which exists between *Mytilicola* and *Piratasta* (Leigh-Sharpe, 1934; Yamaguti, 1939).

Objects of the Investigation

Several methods of approach are open in an investigation of this nature. The ideal method of control would be to prevent infection of the potential host; alternatively a method might be devised which kept the level of infection below the level at which damage is caused to the host; a further possibility would be to find if conditions exist in which the parasite does no harm to its host; less satisfactory would be a method of ridding the host of its parasites for sufficient time for it to recover from the effects of parasitisation. *Mytilicola*, once within the gut of the host, lives in a very stable environment, and to change this would probably mean such violent disturbance that the mussel would also suffer. Indeed, Dutch investigators have found that *Mytilicola* is more resistant to certain environmental changes than its host. At the outset a number of experiments were made to investigate the effect of certain intra-vitam dyes on parasitised mussels, as suggested by Ranson (1951), and the effect of the Dodgson cleansing technique, as suggested by Heldt (1951). The results were not encouraging and these investigations were not pursued further. It was decided that the most hopeful line of approach to control measures would be to determine the relative importance of the various environmental factors governing infection of mussels.

With a view to determining whether conditions occurred in nature which either limited the level of infection, or enabled the mussels to withstand parasitisation, a series of field surveys were made at Poole (Dorset), Falmouth (Cornwall), Plymouth (Devon) and Milford Haven (Pembs.). These may be described as more directed than the surveys reported by Bolster (1954), from which, however, he was able to suggest at least one of the more important factors—level—which is submitted here as established by the present surveys.

SURVEY METHODS

In the field surveys mussels were collected from a wide variety of sites and the local ecological conditions were noted. Wherever possible 20 mussels were examined for parasites from each site. In addition, a condition index (see page 14) was measured for one to four batches of five mussels each where sufficient were available. Every mussel was measured to the nearest mm. below, opened, and its condition assessed on the scale: Good—well filled with meat of good quality; fair—less well filled or meat of poor quality, usually red or orange in colour; poor—little meat, meat watery, mantle transparent. In this way the general condition was assessed. This method had the disadvantage of being somewhat arbitrary, but, since all the assessments were by the same observer, could be used for comparative purposes to the extent of indicating that mussels from one site were substantially better or poorer than those from another.

After removing gills and mantle from the left side, the gut was dissected out of each mussel and opened along its length, with a needle, in a watchglass of water. The parasites were then removed and counted under a binocular microscope fitted with an eyepiece micrometer. They were grouped as juveniles (3 mm. or under), males, females without egg-sacs and females with egg-sacs. Using this method it was possible to examine a sample of mussels in from one to three hours, depending upon the degree of infection.

Since parasites tend to move towards, and finally out of, the anus of the host, if it is kept for prolonged periods (four to five days) out of water, every effort was made to examine the mussels within 48 hours of collection. Only rarely were parasites found free in the mantle cavity of the host; it is believed that the loss in this way was negligible.

When an area was being examined, from which *Mytilicola* had not previously been

reported, mussels were collected from sites at which a heavy infection might be expected if the parasite were present, and also from sites near a possible source of infection, as, for example, quay walls. In new areas, samples of up to fifty mussels were examined by the method described above, and a number were also examined macroscopically, by opening the mussel and exposing the gut by scraping away the overlying tissues with a scalpel or sharp knife. Any suspicious redness in the gut was then examined further.

Using these methods it was possible to examine large numbers of mussels fairly rapidly and to note the effect of certain ecological conditions, and in this way any points of special interest could be subjected to further observations without delay. Three hundred and fifty to five hundred mussels were examined on each survey, the totals of parasites recovered being from a thousand to thirteen hundred on each occasion.

AREAS SURVEYED

Poole Harbour (Fig. 1)

Poole Harbour is a large bay into which the River Frome and several smaller streams discharge, communicating with the sea by a narrow mouth. At high water it presents a large open expanse, with several islands, but at low water very large mud banks are exposed intersected by winding channels.

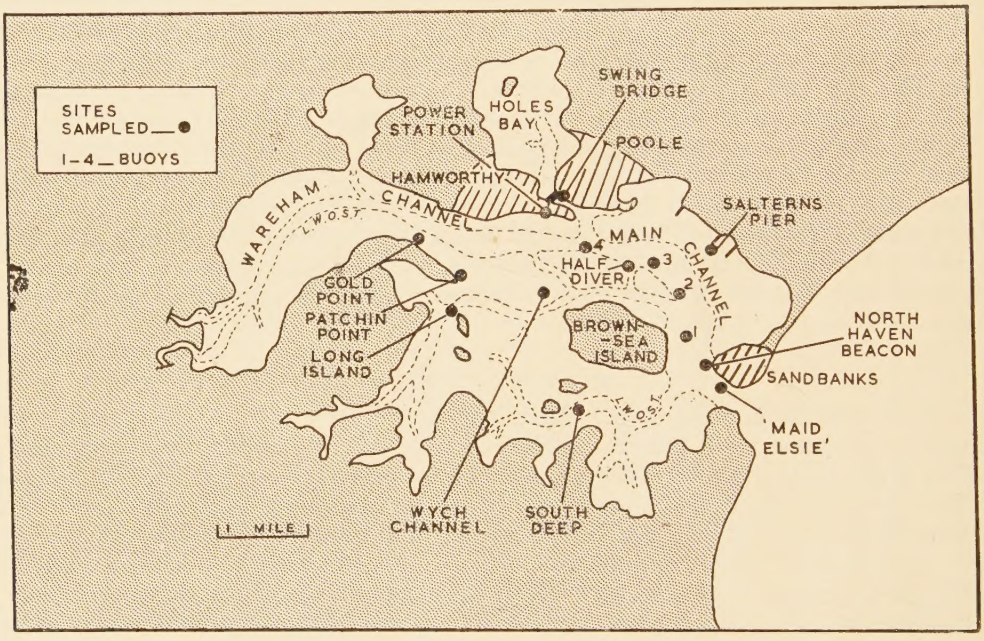


FIG. 1. Sketch map of Poole Harbour showing sites sampled.

Mussels were taken from the following sites:

(i) Long Island. A very thin bed of mussels with many dead shells suggesting that the bed may be declining. Living and dead shells are covered with a brown algal growth. The substratum is a firm mud.

(ii) Patchin Point to Gold Point. An extensive and fairly dense bed of mussels in good condition, with very few dead shells. The substratum is of stones, with soft muddy patches.

(iii) Wych Channel. This was once an extensive mussel bed, but now shows only clumps of mussels and dead shells. The substratum is a firm mud. The bed shows many signs of bait digging, which may be the cause of its decline.

(iv) Buoys and hulks. The buoy chains on the east side of the main channel carried dense colonies of mussels at the time of the survey, those on the west side carried very few. This curious situation probably results from variation in water movements. Mussels were collected from the main channel buoys, and from the *Maid Elsie*, a hulk moored near the harbour entrance.

(v) Pier and bridge piles, beacons and booms. Many piles and beacons support dense growths of mussels. " Beacons " and " booms " in this area are upright posts, usually pieces of railway line, used to mark the edges of the channel.

(vi) South Deep. Some mussels were dredged by a colleague, Mr. P. R. Walne, from the channel known as the South Deep.

Plymouth (Fig. 2).

Mussels were found to be sparsely distributed in this region. Samples were taken from the estuaries of the Tamar and Lynher Rivers at the following sites:

A.—River Tamar.

(i) Weir Quay. This is a disused quay about four miles above Saltash bridge with a few mussels in the crevices and on stones on the foreshore, the highest point upriver at which mussels were found in the Tamar.

(ii) Thorn Point. A few mussels were found on the remains of a groyne about a mile and a quarter below Weir Quay.

(iii) Buoys. Mussels were examined from buoys between Neal Point and Torpoint.

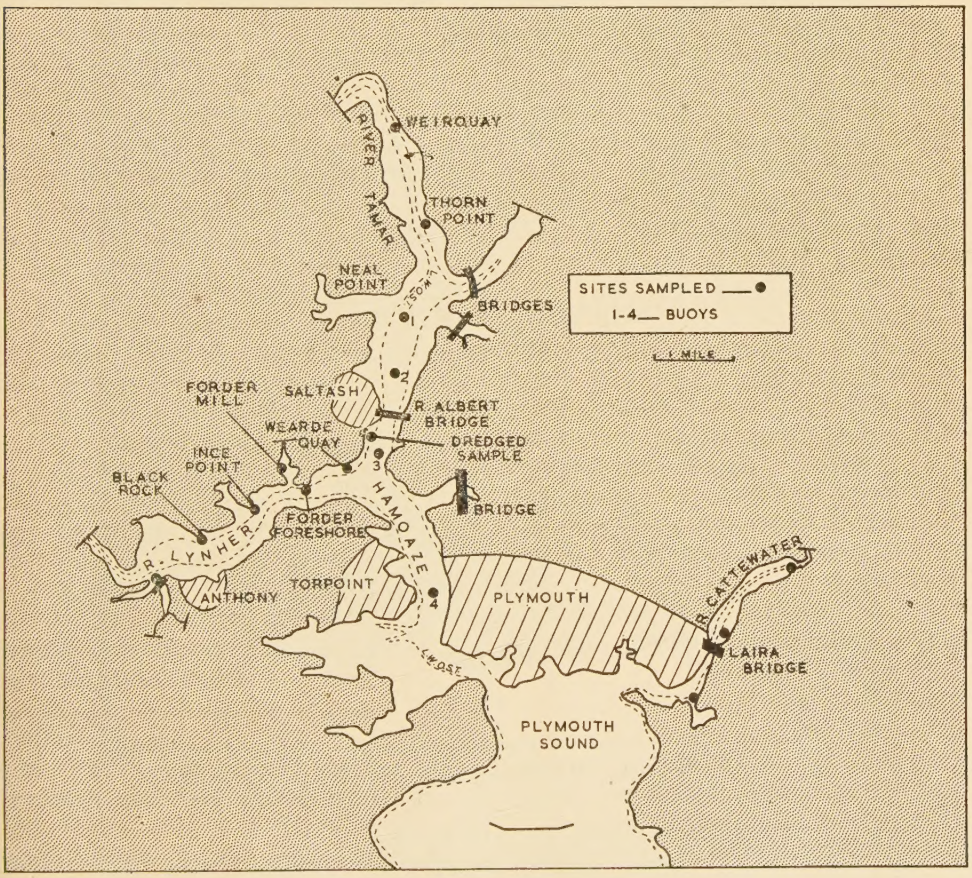


FIG. 2. Sketch map of the Plymouth area, showing sites sampled.

B.—River Lynher.

(i) Black Rock. A few mussels were taken from an outcrop of rock. This is the highest point upriver at which mussels were found in the Lynher.

(ii) Ince Point. Mussels were found on the remains of a wall about a mile downstream from Black Rock.

(iii) Forder Creek. A few mussels occur on the foreshore about three-quarters of a mile downstream from Ince Point. Mussels were also available in quantity from the sluices of a disused mill nearby.

(iv) Wearde Quay. A few mussels were found on the walls of a disused quay in the mouth of the River Lynher.

(v) Anthony. Mussels occurred on the walls of a sluice draining a basin into the Lynher River.

River Fowey (Fig. 3)

This river receives as tributaries the River Lerryn, and smaller streams, which flow in through Penpoll Creek, Mixtow Pill and Pont Pill. There are numerous harbour installations in the lower reaches of the river.

(i) New Quay. This is the main jetty for loading china clay and is approximately one mile above Fowey. Its piles and supports carry dense colonies of mussels.

(ii) Boddinick. The foreshore is of stones and carries a few mussels.

(iii) Buoys. Those examined were moored in the lower reaches of the river, and all carried mussels, often in dense colonies.

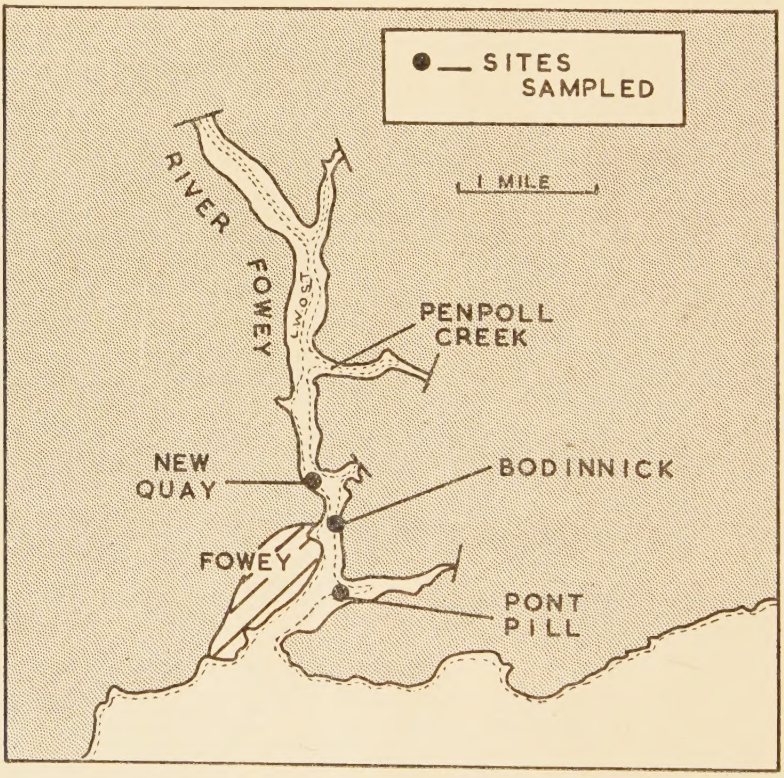


FIG. 3. Sketch map of the Fowey area, showing sites sampled.

Carrick Roads, Penryn, Fal and Truro Rivers (Fig. 4)

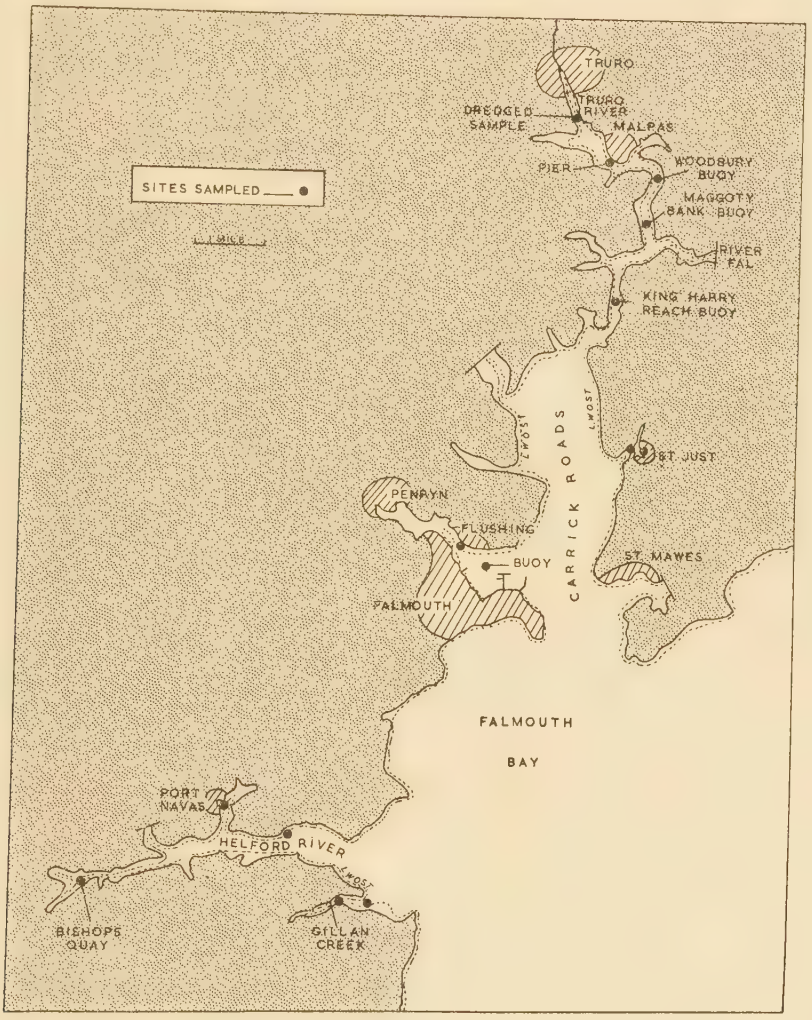
The Rivers Fal and Truro join to form a long deep estuary, terminating in Carrick Roads (Falmouth Harbour). The Penryn River flows into Carrick Roads near their mouth. There are numerous small creeks entering all these rivers.

(i) Flushing, Penryn River. Mussels were present in small colonies on quays, piers and walls.

(ii) Malpas, Truro River. This is the highest point upstream to which oysters extend. Small colonies of mussels were found on the quay.

(iii) Buoys. In Falmouth harbour (Carrick Roads) and the Truro River most of the buoys carried mussels.

(iv) St. Just. This creek, opening off Carrick Roads, has a stony foreshore which carried a few scattered mussels.



g. 4. Sketch map of Carrick Roads, Penryn, Fal and Truro Rivers, and the Helford River, showing sites sampled.

elford River (Fig. 4)

The Helford River receives a number of small creeks, but has a relatively small catchent area; mussels are not abundant and the existing colonies have been reduced in recent ars.

(i) Quays. A few mussels were collected from Porth Navas and Bishops Quay.

(ii) Gillan. A short creek opening near the mouth of the Helford River; the stony foreshore carried a few mussels.

Milford Haven (Fig. 5)

The area includes a main estuary comprising Milford Haven and the River Cledda It receives numerous tributaries, including the Pembroke River, which enters throu Pennar Gut, and the Cresswell River, which enters the main estuary at Lawrenny in common estuary with the Carew River. Inland, the main estuary extends to and beyo Haverfordwest as the West Cleddau.

(i) Main estuary. Mussels were found to occur in colonies on the foreshore, at abo the level of low water of spring tides, throughout the estuary from Angle Bay to Lit Milford wherever the substratum was favourable.

(ii) Pembroke River. Mussels were found on suitable substrata from Pennar Mou to Turks Castle.

(iii) Cresswell River. Mussels occur on suitable sites from Lawrenny to about t miles upstream.

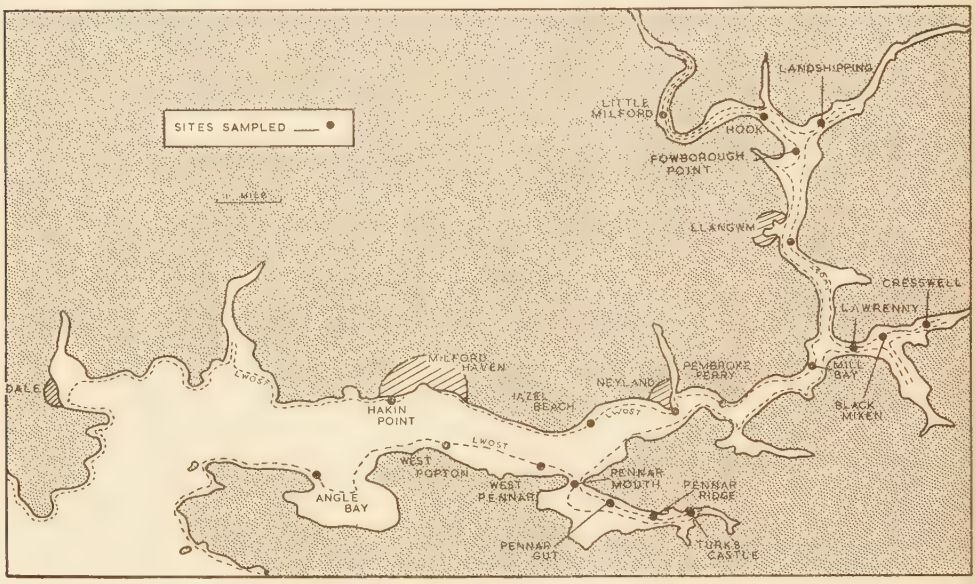


FIG. 5. Sketch map of the Milford Haven estuary showing sites sampled.

THE INFLUENCE OF ENVIRONMENTAL FACTORS

Position of Mussels in Relation to the Sea Bed

Mussels were taken from different levels at a number of suitable sites, such as walls, p and bridge piles, buoys and steeply sloping banks. The infection levels of higher a lower samples are compared in Table 1, and the infection level on buoys and hulks compared with that of bottom-living mussels in Table 2.

From Table 1 it is seen that mussels raised from the bottom are less infected than th not so raised. The average infection of the raised mussels was 4.6, and that of the lo samples 5.9 parasites per mussel. In the case of mussels on floating objects, Table 2, t difference was even more marked. The average infection of buoyed mussels was 0 while the examination of nearby bottom-living mussels gave an average of from 1.3 9.4 parasites per mussel for samples of 20 mussels. In only two cases was the infecti level of the higher sample greater than that of the lower sample. In the first, at Lo Island, Poole, there was only a difference of 0.75 feet in the level of the two samples wh were taken from a rather gently sloping bank. In the other case, Malpas Pier, Truro Riv the difference in levels was considerable, and no explanation was apparent.

The difference in infection rate is most probably due to the habit of the copepodid st of the parasite, which, as mentioned earlier, tends to swim near the bottom. Further,

TABLE 1.

Effect of raising mussels from the sea bed.

Site	Low level				High level					Remarks
	Average length cm.	Average infection	Estimated condition	Exposure hrs. per day	Average length cm.	Average infection	Estimated condition	Exposure hrs. per day	Height above lower sample	
									ft.	
Poole.										
North Haven Beacon	6.6	**8.15**	Good	L.W.O.S.T. only	5.3	**2.8**	Good	12	4	Upright post
Half Diver Boom	6.4	**7.7**	Good	L.W.O.S.T. only	5.0	**4.9**	Good	12	4	Upright post
Patchin Point	6.6	**8.3**	Good	2-4	5.6	**6.5**	Good	12	2	Mussel bank
Wych Channel	6.2	**6.9**	Good	2-4	—	—	—	—	—	Mussel bank
Saltern Pier	—	—	—	—	5.3	**1.3**	Good	12	—	Pier Piles
Swing Bridge	—	—	—	—	5.4	**3.2**	Good	12	—	Bridge Piles
Long Island	6.0	**5.5**	Fair	2-4	5.8	**8.7**	Good	3-5	0.75	Mussel bank
Helford River.										
Bishops Quay	5.2	**6.8**	Fair	2-4	5.2	**5.3**	Fair	4-6	3	Quay wall
Port Navas Quay	4.6	**6.3**	Fair	2-3	4.3	**5.0**	Fair	4-5	4	Quay wall
Fowey River.										
New Jetty	6.2	**2.6**	Good	L.W.O.S.T. only	5.9	**0.7**	Fair	12	7	Jetty Piles
Penryn River.										
Flushing	7.2	**2.8**	Fair	10-11	5.8	**2.7**	Fair	11-12	4	Wall
Truro River.										
Malpas Pier	6.4	**4.4**	Fair	2-4	5.7	**5.2**	Fair	4-6	6	Pier wall

the higher mussels are submerged for a shorter period they are also less exposed to infection. The very light infection of mussels on buoys, hulks and floating objects, generally, as shown in Table 2, suggests that the swimming habit of the copepodid is the more important factor, since buoyed mussels are normally continuously submerged and thus exposed to infection 24 hours per day.

TABLE 2.
Infection of mussels on buoys compared with bottom-living mussels.

Site	Buoy			Nearest bottom-living mussels			
	Average length cm.	Average infection	General condition	Average length cm.	Average infection	General condition	Distance from buoy
Poole.							
1.	4.0	0	good		1.3 to 8.15		200 to 500 yds.
2.	4.3	0	,,				
3.	4.0	0.1	,,				
4.	4.0	0	,,				
Maid Elsie (hulk) ..	6.0	1.15	,,	6.6	8.15	good	100 yds.
Truro River.							
Maggoty bank ..	5.4	0.25	good	7.4	9.4	fair	1,000 yds.
Woodbury	5.4	0.15	,,	6.0	4.3	,,	1,000 yds.
King Harry Reach..	4.6	0.05	fair	—	—	—	—
Falmouth harbour..	6.0	0.35	good	—	—	—	—
Fowey River.							
Off Wiseman Point	6.2	0.2	good	6.2	2.6	good	100 yds.
Pont Pill 1	5.0	0.15	,,	6.1	6.6	fair	1,000 yds.
Pont Pill 2	7.2	0.5	,,				
Tamar River.							
Neil Point	7.7	2.0	good	—	—	—	—
Above R. Albert Bridge	5.7	0.9	good	—	—	—	—
Saltash	5.4	0.9	fair	6.3	5.3	good	100 yds.
Off Torpoint ..	5.3	0.1	fair	—	—	—	—

Effect of Water Movement

It is very difficult to make an accurate estimate of average rate of water movement in the field without a number of observations, using rather complex apparatus, over a period of time. However, by observing the rate of movement of pieces of driftwood, and especially by the examination of the bottom deposits, combined with a knowledge of local topography, it was usually possible to say whether the water at one point generally flowed faster or slower than at another point nearby. Particularly, in the narrow mouth of an otherwise wide creek, the water will flow much more rapidly than in the body of the creek itself. Such conditions occurred at Gillan and St. Just (see Table 3 and Fig. 4). Here mussels were taken from the well-scoured mouth of the creek, and compared with those from the more muddy open parts of the creek. At Forder and Anthony (Table 3 and Fig. 2) mussels were taken from sluices draining large basins. At Poole Bridge (Table 3 and Fig. 1) a narrow channel drains a large area (Holes Bay) and hence water movement is rapid. Patchins Point, Long Island and Wych Channel are subject only to the slow flow of tide over the beach; the rise and fall at spring tides is only four and a half feet.

It will be observed in Table 3 that mussels in slow moving water are more heavily infected than those in the faster moving water.

Density of Host

Table 4 shows a comparison of the infection level for dense mussel beds with that of nearby beds where the mussels were more widely separated. Within the limits of the beds examined there did not appear to be any significant effect of density on infection. The beds investigated included some which were of such a low density as to be useless for commercial purposes, and others which were overcrowded.

TABLE 3.

Effect of water movement on level of infection of mussels.

Site	Fast moving water			Slow moving water		
	Average length cm.	Average parasite content	Condition	Average length cm.	Average parasite content	Condition
elford River.						
Gillan	5.8	1.9	good	6.8	5.6	fair
al River.						
St. Just	5.5	2.4	,,	7.1	3.6	,,
ynher River.						
Forder	6.1	3.9	fair	7.9	6.3	,,
Anthony	6.4	3.8	good	6.4	5.5	good
oole.						
Patchin Point	—	—	—	6.6	8.3	,,
Long Island	—	—	—	6.0	5.5	fair
Wych Channel	—	—	—	6.2	6.9	good
Poole Bridge	5.4	3.2	good	—	—	—
Poole Power Station*	5.9	0.75	,,	—	—	—

* Obtained from duct of cooling system of Poole Power Station, by courtesy of British Electricity Authority. ubject to continuous fast flow of water.

ffect of Salinity

The main survey with respect to salinity was made at Milford Haven (Fig. 5). In rder to eliminate other effects, as far as possible, all samples were taken from the foreshore, t about low water mark of ordinary spring tides. Sites of obviously faster or slower moving ater were avoided where possible, although this was not possible at Fowborough Point, 'ennar Mouth, Pennar Gut and Lawrenny (Fig. 5). At Fowborough the river widens ppreciably and here water movement would be sluggish. At Pennar Mouth, Pennar Gut nd Lawrenny, the samples were, of necessity, taken from fairly narrow channels forming ıe entrances to wide creeks so that the parasite content of the mussels was probably lower s the result of rapid water movement. Results are shown in Figs. 6 and 7.

TABLE 4.

Effect of host density on level of infection.

Dense Bed		Thin Bed		Distance apart
Site	Average Parasites per mussel	Site	Average Parasites per mussel	
Milford Haven.				
Fowborough Point	11.7	Landshipping ..	11.7	800 yds.
Hook	9.3	Little Milford ..	8.2	2 miles
Mill Bay	8.3	Lawrenny ..	8.5	1.000 yds.
Pembroke Ferry ..	11.45	Neyland	15.0	1,000 yds.
Poole.				
Patchin Point ..	8.3	Long Island ..	5.5	1,000 yds.

Salinities in Figs. 6 and 7 were calculated from hydrometer readings, using Knudsen's ables. Examination of these figures shows that there is a steady rise in parasite content rom the marine end of the estuary to Neyland, approximately the lowest point at which

substantial influence of fresh water is evident. Further upstream there is a decline parasite content in the less saline regions of the estuary. In the River Cleddau it is probab that mussels would occur above Little Milford but for a lack of suitable substratum. Th rise in parasite content at Fowborough is not statistically significant, and may be du either to chance or more probably to the widening of the river at this point, which woul lead to slower water movement and an improved chance of infection. A decline in parasi content similar to that observed in the less saline regions of the River Cleddau was als found in the upper reaches of Pennar Gut and the Cresswell estuary (Figs. 5 and 7).

Fig. 8 shows the results of a survey with respect to salinity in the Rivers Lynher and Fa In these estuaries it was not possible to collect such a satisfactory series of samples as Milford Haven (Figs. 6 and 7).

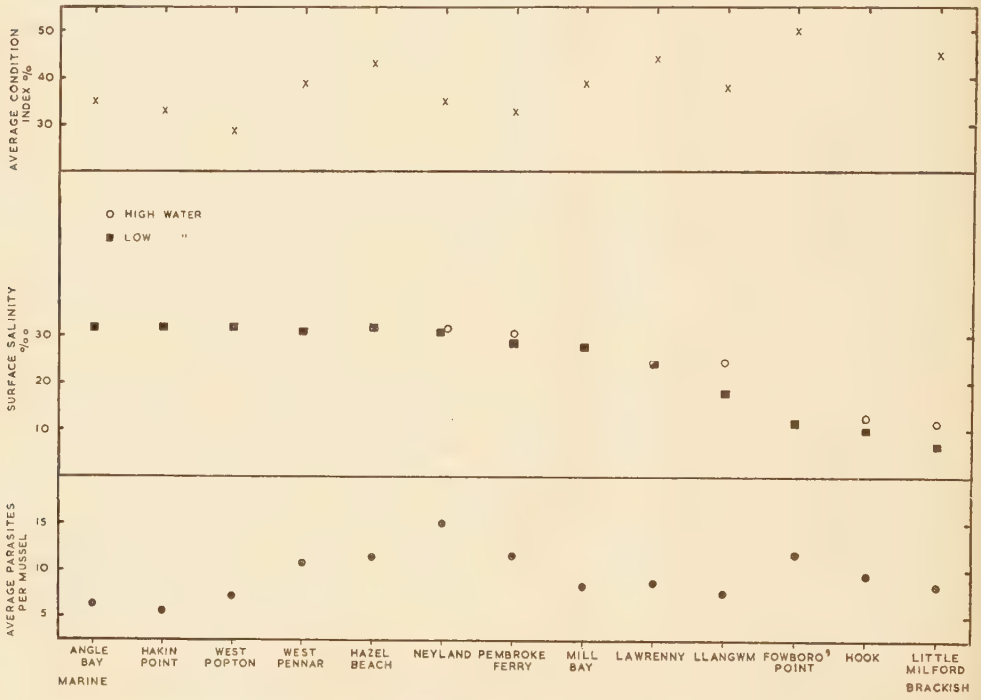


FIG. 6. Average parasite content, and index of condition of mussels, and the surface salinity, a sites sampled in the Milford Haven and River Cleddau.

It is very difficult to generalise about conditions at particular points in an estuar because of tidal and seasonal fluctuations, but it does appear that *Mytilicola* is suited by slight reduction of salinity, and is less favoured by fully marine conditions or very lo salinity water. The results from the Rivers Lynher and Fal (Fig. 8) appear to support thi conclusion, but it was not possible to collect samples from similar sites throughout thes estuaries, hence the effect of salinity may be obscured by the influence of other factors such as water speed.

The Effect of Situation on the Condition of Infected Mussels

At a number of stations the index of condition of a batch of mussels was measured, t find if ecological conditions exist which enable the mussel to withstand the adverse effect of parasitisation. The index of the condition used (Cole and Baird, unpublished) is th percentage of the internal shell volume occupied by meat, the volume being measured b displacement. Mussels with a condition index of 50-60 are marketable, while those giving an index over 60 may be said to be in excellent condition. The results are summarised i Table 5 (see also Fig. 6). It is clear that parasitisation is not necessarily followed by loss o

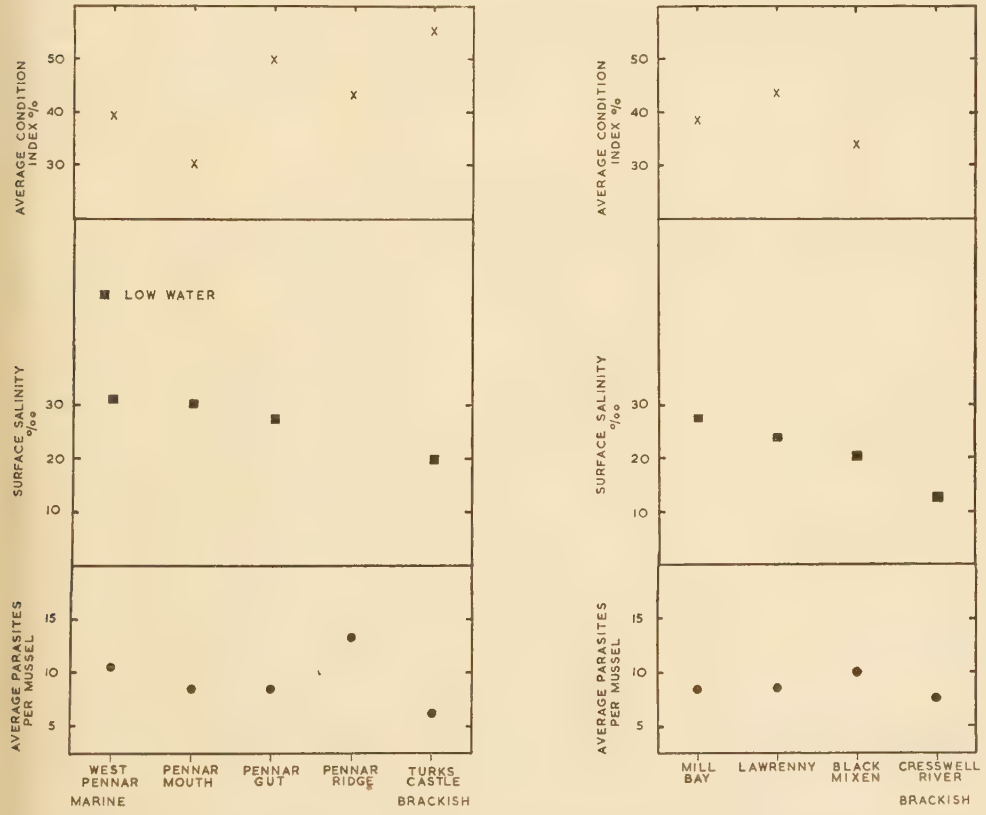
ndition, although it is of interest to note that the most heavily parasitised sample showed e lowest index of condition. It appears that if conditions for the mussels are good (i.e. undant food, little silt, cool water) they can withstand a fairly heavy infection by *Mytilicola* ithout loss of condition. If conditions are not good, e.g. on densely populated beds on dal flats in very hot summers, the presence of *Mytilicola* is sufficient to cause serious harm mussels, resulting in loss of condition, abnormal metabolism and even death. Numerous orkers have attempted to determine exactly how *Mytilicola* damages its host, but the issue mains unsettled.

Further evidence regarding the influence of ecological conditions on growth and flesh ntent of mussels is given in the section below describing the field experiments.

FIELD EXPERIMENTS

n order to examine the rate at which mussels become infected and the final level of rasitisation reached, under better controlled conditions than are usually obtainable nong naturally occurring mussels, series of field experiments were set up at Poole and owey in May and June, 1953, respectively. These experiments comprised the placing of ussels on rafts, stakes and the flat, at Poole, and on rafts and stakes at Fowey.

The rafts consisted of wooden frames, 6 ft. × 2 ft. 6 in. × 5 in. deep, supported by oil rums attached to their ends by metal strips. Each raft was divided into three compartments, one for uninfected *Mytilus edulis* from Conway (Caernarvonshire); one for infected *Mytilus edulis*, obtained locally; and one for mussels from Padstow (Cornwall). These st were used because they strongly resemble *M. galloprovincialis*, the mussel of the Mediterranean Sea. Reports from the Mediterranean state that, although this is the site



G. 7. Average parasite content and index of condition of mussels, and the surface salinities, at sites sampled in Pennar Gut (left) and the Carew-Cresswell estuary (right), tributaries of Milford Haven.

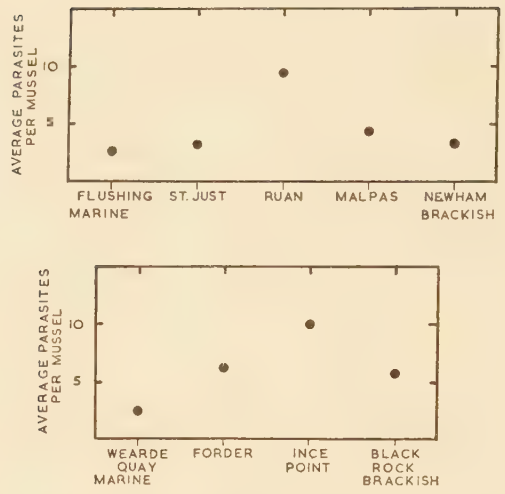


FIG. 8.
Average parasite content of mussels at sites sampled in the Rivers Fal (above) and Lynher (below)

of origin of *Mytilicola*, mussels there are only lightly infected. If this is so, there may b some natural immunity possessed by *M. galloprovincialis*, and one of the purposes i setting up the experiments was to compare the levels of infection under field condition in the two species of *Mytilus* (assuming the Padstow mussels to be *M. galloprovincialis* In laboratory experiments it did not appear that any differences existed.

The stakes used were rough wooden poles, about four inches in diameter. Mussel were attached to them by nets and covered about four feet of each pole. Uninfected *M. edulis* from Conway, local infected *M. edulis* and Padstow mussels were used on separat poles.

TABLE 5.
Index of condition of infected mussels.

Site	Situation	Average infection	Index of condition	Exposure hrs. per day
Poole.				
Patchin Point	Bed on foreshore	8.3	51.6	2-4
Wych Channel	Bed on sandbank	6.9	53.2	2-4
Buoy Chain	Buoyed	0.4	47.3	nil
North Haven Beacon	Raised on upright post	8.15	62.2	L.W.O.S.T. only
Half Diver Beacon	Raised on upright post	7.7	68.0	L.W.O.S.T. only
Maid Elsie (hulk)	On floating object	1.15	50.6	nil
Fowey.				
Boddinick foreshore	Sparse bed on foreshore	6.6	55.0	0-2
Fal River.				
Woodbury Buoy	Buoyed	0.15	54.5	nil
Malpas	Dredged from bank	6.5	42.9	nil
Lynher River.				
Anthony	Wall of sluice	7.6	46	6-8
Ince Castle	Remains of wall	10.2	50	2-3
Milford Haven.				
Neyland	Foreshore	15.0	37.5	L.W.O.S.T.
Hazel Beach	Foreshore	11.3	44.2	L.W.O.S.T.
Fowborough Point	Foreshore	11.7	50	L.W.O.S.T.

TABLE 6.
Results of field trials in Poole Harbour.

	Off Brownsea Island in fast moving water		Off Brownsea Island in slow moving water		Upstream in Wareham Channel		Gold Point	
	Average Parasites	Condition Index	Average Parasites	Condition Index	Average Parasites	Condition Index	Average Parasites	Condition Index
Conway mussels on raft	2.2	63.0	3.5	60.6	4.0	58.0	—	—
Padstow mussels on raft	2.9	65.2	3.1	71.0	6.2	—	—	—
Local mussels on raft	6.1	60.5	6.8	65.0	6.8	69.0	—	—
Conway mussels on post	7.0	*	9.8	64.0	7.6	*	—	—
Padstow mussels on post	7.0	*	*	*	—	—	—	—
Local mussels on post	4.5	*	7.8	*	—	—	—	—
Conway mussels on flat	—	—	—	—	—	—	8.4	43.0
Padstow mussels on flat	—	—	—	—	—	—	12.2	41.3
Local mussels on flat	—	—	—	—	—	—	12.4	42.9

* Poor survival, insufficient mussels available for measurement to be made.

When making flat layings a suitable piece of ground was cleared of local mussels and the test mussels were spread in their place. The area was marked with stakes.

At Poole, rafts were moored and stakes were set up in fast and slow moving water off Brownsea island (the sites being selected on the advice of the Harbour Authority) where there can be little if any, reduction of salinity due to inflowing fresh water, and up the Wareham Channel, off Gold Point, where there is substantial fresh water influence (local information and observations of flora and fauna). These sites were at about the level of low water of spring tides. A flat laying was made at Gold Point at about the same level, near a natural mussel bed.

At Fowey, rafts were moored in the lower reaches of the river, in Pont Pill, where there is insignificant salinity reduction, and in Penpoll Creek. Stakes were also set up in Penpoll Creek and although these were actually placed at about mid-tide level, which was rather higher than intended, and were exposed for very long periods, the mussels did well. Padstow mussels were not used at Fowey.

Results are summarised in Tables 6 and 7. At Poole, survival on the stakes was very poor; the stakes were found to be covered with a dense mat of sea squirts when raised. Despite the poor survival of mussels at Poole, and the low level of infection of the experimental mussels at Fowey, it is obvious that the conclusions drawn from the field surveys

concerning the effects of the raising of mussels, speed of water movement, and of salinity, are supported by these experiments. In addition it is clear that rafts and stakes provide a suitable environment for mussels, provided that they are submerged for sufficient time; mussels in these positions grow well and are in fine condition.

On comparing the parasite content of local mussels at the close of the experiment with that of originally uninfected mussels it was observed that the level of infection of the former was usually higher, indicating that at least some of the original parasites were still present. This shows that the parasites can survive at least from May to November, the duration of the Poole experiment.

The comparison of infection rates of *Mytilus edulis* from Conway and the presumed *M. galloprovincialis* from Padstow indicates that the Padstow mussels do not possess any natural immunity from infection. The average infection of relaid Conway mussels from four sites at Poole was 4.1 parasites per mussel, while Padstow mussels from the same sites carried 4.8 parasites per mussel. The experiment was not of long enough duration to determine whether the Padstow mussels could maintain condition and growth rates under parasitisation better than the known *M. edulis*.

TABLE 7.
Results of field trials in Fowey estuary.

	Downstream		Upstream	
	Average Parasites	Condition Index	Average Parasites	Condition Index
Conway mussels on raft ..	0.0	69.0	0.4	67.5
Local mussels on raft	1.0	66.0	1.25	65.0
Conway mussels on post ..	—	—	0.32	45.3
Local mussels on post.. ..	—	—	1.5	50.2

APPLICATION OF RESULTS TO CONTROL MEASURES

As *Mytilicola*, which can undoubtedly cause a great deal of harm to mussels, is already widespread in Great Britain and may quickly extend to the commercial mussel beds, it is very desirable to devise some form of control. Since the parasite may be carried in ship-borne mussels, distributed by currents in its free-swimming stages, or conveyed from place to place in relaid mussels or other shellfish, it is not possible to confine it to the areas already infested. Where practicable, mussel-free zones may be created to provide a barrier to natural spread, but this method of control has a very limited application in Britain. Hence action taken to combat the effect of the parasite must aim, in the main, at reduction or elimination of infection once it has reached a bed, or the prevention of infection by local measures.

Methods of ridding the mussels of their parasites, by chemical or similar treatment, would involve either treating the water over the mussels with a suitable substance, if one could be found, or the relaying of mussels in tanks of treated sea water and their return to the beds for fattening. Either method would be costly to operate, and it would be necessary to repeat the treatment at intervals to prevent heavy reinfection.

The question therefore arises whether control by ecological or cultural technique is both possible and practicable. There are two possibilities, firstly, to prevent or restrict infection, and secondly, to provide such favourable conditions that infected mussels can still grow and fatten satisfactorily. In the field surveys undertaken for this investigation no situation was found in which freedom from infection could be guaranteed, although buoyed mussels were only very lightly infected. They were also in good condition, thin-shelled and very fast growing. However, the cost of constructing and maintaining rafts for mussel culture is likely to prevent this method from becoming a practical proposition for the mussel farmer.

It was also observed that mussels living in fast moving water, in water which was of full linity or water much reduced in salinity, and also mussels raised from the bottom, all owed a low susceptibility to infection. Mussels in fast moving water and raised from the ttom are usually in good condition and quick growing. Those mussels examined during e survey from water of much reduced salinity were also fat, but it is not known whether is observation is generally applicable. It seems certain, however, that the optimum linity for growth and condition in mussels is substantially below that of full sea water.

It would seem possible, therefore, to restrict the level of infection by cultivating mussels the upriver parts of an estuary or in fast moving water. Unfortunately, this method of ntrol would limit rather severely the area available for mussel culture, and although it ight be satisfactory where an estuary supported only a small mussel industry, it could rdly be considered applicable to areas such as The Wash or Morecambe Bay.

The most helpful line of approach to control of *Mytilicola* on a large fishery would seem hinge upon the fact that mussels raised on pier piles and similar structures are less avily infected, and, as a rule, in better condition than those growing on the flat foreshore a comparable tidal level. If mussels could be grown raised in some way from the sea d the infection would be reduced, although not eliminated. Since raising mussels from e bottom, or growing them in fast moving water would not prevent a slight infestation ith parasites, then it might be suggested that these mussels would be liable to lose ndition. However, although Meyer and Mann (1951) suggest that with three parasites more, loss of condition may result, the observations of Cole and Savage (1951) suggest at up to ten parasites may be tolerated without serious effect. This latter observation lated to mussels from the Blyth estuary, Northumberland, where conditions, generally eaking, are not favourable for mussels. In the surveys described above, mussels with erage infections of 8.15 and 7.7 parasites respectively (Table 5), a heavy infection, each owed a condition index of over 60 per cent. As mentioned earlier, such a high index of ndition is only obtainable from mussels in prime condition; thus, even heavy infections of *ytilicola* may not always be harmful. It is suggested that if environmental conditions r mussels are favourable, with abundant food, little silt and cool water, then the mussels not show the ill effects of parasitisation by *Mytilicola*. On the other hand, if environental conditions are poor with little food, much silt and warm water, then the mussels are able to withstand the effects of parasitisation and may rapidly lose condition and die.

The cultivation of mussels raised from the sea bed has been practised in France, in the ay of Aiguillon, for approximately 700 years, and also for a very long period in the editerranean. These systems have been described by Herdman (1894) and Lambert 936) but a short account of the techniques will not be out of place here.

Mussel spat is collected on single posts about 6 ft. in height driven into the shore at out low water mark of ordinary spring tides. The spat is removed from these posts hen it is about 1 in. in length and transferred to fences constructed of posts interwoven ith brushwood. The clumps of spat are lodged in the interstices of the fence and as they ow they spread out and occupy the entire surface. The fences are sited so that the upperost mussels are covered by the sea for about eight hours at each tide and since, both for nvenience and in order to carry a worthwhile stock of mussels, the fences should be about ft. high, a tidal range of about 16 ft. is necessary for this type of culture. Such a dal range is not uncommon around British shores, but an alternative method can be used here the tidal range is insufficient for fences. In this second method, goal-post like frames e erected so that their tops are submerged for the necessary 16 hours per day, and mussels e grown suspended on ropes. The spat is collected as described above, and is then attached the ropes by laying the mussels around the ropes in shallow troughs placed on the foreore for a few days. The mussel spat attaches itself to the ropes by byssus threads and the pes are then tied to the frames. Spat can also be collected by suspending ropes horintally in the water between poles.

According to French workers, mussels grown on fences reach marketable size in their ird year, i.e. at about thirty months of age. Mussels grown in this manner are in fine ndition.

This French system of culture would, in the opinion of the writer, suffice for the con of *Mytilicola*. It would keep down infection by raising the mussels and provides excel conditions for growth and fattening; moreover, it is well tried in practice. Its applicatio Britain would open up large new areas for mussel culture, as the method is to a large ex independent of the nature of the substratum, and would enable better use to be mad many existing mussel beds by increasing both the stock of mussels and the rate of gro thus resulting in a more rapid turnover. As a method of control it would not be infall as environmental conditions, particularly water temperature, cannot be controlled. exceptionally warm summers, water temperatures may rise to such a level as to lea heavy infestation of fenced mussels and some loss of condition, but in such sum catastrophic mortalities are likely to occur in mussels on the flat (Korringa, 1951 Bolster, 1954).

SUMMARY

The importance of *Mytilicola*, its spread to and around the shores of Britain, its metho dispersal, life history and hosts are briefly discussed.

A number of extensive field surveys produced evidence to show that mussels ra from the sea bed, or in fast moving water or at either end of an estuary are less hea infected than bottom-dwelling mussels, those in slow moving water or those in the mi region of an estuary respectively. These conclusions are supported by the results of f trials.

It is concluded that control of the parasite is possible by using culture methods sim to those practised in France and Italy on stakes, fences or ropes. By growing mussel selected sites in fast moving water or at the brackish water end of an estuary, good qua mussels may be cultured on the flat. In addition to restricting the level of infection, s culture methods appear to provide conditions which enable the mussels to withst parasitisation without serious loss of condition.

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